

## OPTIMAL DESIGN OF PIPE NETWORK FOR CONVERTING EXISTING NETWORK INTO 24 X 7 WATER SUPPLY SYSTEM NETWORK

M. M. Pawar<sup>1</sup> & N. P. Sonaje<sup>2</sup>

<sup>1</sup>Research Scholar, Department of Civil Engineering, SVERI's College of Engineering, Pandharpur, India

<sup>2</sup>Research Scholar, Department of Civil Engineering, Government Polytechnic, Gadchiroli, India

### ABSTRACT

The pipes used in water distribution system are the largest investment. The design, modeling and optimization of pipes in water supply system are very important from an economic point of view. Therefore, in this paper, optimal design of pipe network for converting existing network into 24 x 7 water supply system networks is carried out for reducing the cost using Water GEMS software. Initially, analysis of existing water supply network system is carried out for one zone (Takali Zone-10) from Pandharpur region. The effect of forecasted population on the demand, head loss gradient and pressure development is studied. Further, cost optimization of pipe network is carried out for proposed 24 x 7 water supply system by using Darwin optimization approach, which is based on genetic algorithm. This analysis is carried out for immediate stage-2015, intermediate stage-2030 and final stage-2045. From the analysis, it is observed that, as population increases from year 2015 to 2045, the demand, head loss gradient and pressure development increases. From the Darwin optimization approach, it is observed that the maximum cost reduction of 33.45% is achieved.

**KEYWORDS:** Water Distribution Networks, Demand, Pressure; Head Loss, Cost Reduction, Optimal Design

---

### Article History

**Received: 19 Nov 2019 / Revised: 23 Nov 2019 / Accepted: 30 Nov 2019**

---

### INTRODUCTION

Water is the very critical resource issue of our lifetime. Population growth, economic development, environmental concerns and reduction in freshwater supply in the urban areas pose serious problems to water resources planning and management. Demand for water consumption has been ever-increasing in many municipal areas, and climate change around the world simultaneously causes drought periods in some areas and at the same time flood situation in other area. WDSs represent a vast infrastructure worldwide, which is critical for contemporary human existence from all social, industrial and environmental aspects. As a consequence, there is pressure on water organizations to provide customers with a continual water supply of the required quantity and quality at a required time [5].

A distribution system is a network of interconnected pipes, valves, pumps, tanks and reservoirs, and can span an extensive geographic area to serve multiple municipalities. WDS can be assimilated to networks (or graphs) from a few hundred nodes to thousands or millions nodes in the case of large cities. Traditionally, these complex systems were built with different redundancy degrees, both in topological (more paths to reach the same nodes) and energy (node pressure

higher than design pressure) meaning, in order to give network reliability against mechanical and hydraulic failure [6].

The municipal infrastructure construction is an integral part of urban construction, while the urban water supply network (WSN) is the lifeline of construction projects. Since water supply network is concealed in the underground throughout the years, and it is not easy to determine the operational state of pipe network accurately, so it is exceedingly difficult for the construction as well as maintenance of water supply network with less information about the operational state of water supply network and the hysteresis of getting information. [1]

The pipe network of water supply scheme represents the largest investments for the deployment. Thus, their design is to be done in such a way that the cost of networking should be minimum after satisfying the quality standards of pressure and velocity [2]. The calculation of these parameters in looped networks is performed using a simultaneous solution of a system of equations, which are primarily non-linear. The deterministic solution is difficult to obtain and usually requires the linearization of hydraulic equations, which was virtually impossible until recent computational advances [3].

However, even with the development of software for hydraulic modeling, the design of water supply networks continued to depend on the engineer's experience and expertise. To avoid this dependence and the uncertainties involved in this design process, the hydraulic model was associated with optimization techniques to obtain the network design with minimum costs [4].

The proposed multi-objective design, taking into account energy consumption, demand variation and pressure deficiency in addition to pipe costs to obtain more realistic scenarios of network design.

Traditionally, water distribution network design, upgrading, or rehabilitation is based on engineering judgment. However, in the last three decades, a significant amount of research has focused on the optimal design of water distribution networks. Initially, researchers used linear programming to optimize the design of a pipe network [14]. Subsequent studies applied nonlinear programming to network design problems. Some examples include the optimization of looped pipe networks [15] or the development of models that simulate pumps, tanks and multiple loading cases [16].

From the literature, it is observed that design of water supply network system contribute significantly to the overall expenditure of the same. It is also observed that proper and systematic design, modeling and optimization of network system are necessary.

This paper tries to design 24 x 7 water supply, modeling and optimization of network system by using WaterGEMS software for the small religious important town **Pandharpur** in Maharashtra, India. Initially, manual analysis of Existing Water Supply System of Pandharpur City's one zone (Takali) out of 13 zones of Pandharpur town has been carried out for proposed stages, viz. immediate stage-2015, intermediate stage-2030 and final stage-2045. Further analysis is carried out by using Darwin approach to obtain optimal design of pipe network of existing system based on genetic algorithm. For optimization study, few constraining parameters are considered, viz., demand, head loss gradient, pressure and pipe diameter.

### Site Location

Pandharpur is a pilgrimage town on the bank of Bhima River in Solapur District, Maharashtra, India. It is connected by asphalt road to all district places in Maharashtra. This town is located at latitude 17°40'24.84" N longitude 75°19'31.38" E. Bhima River flowing along the northern boundary of the town takes sharp turns of 90 degrees and flows along Eastern

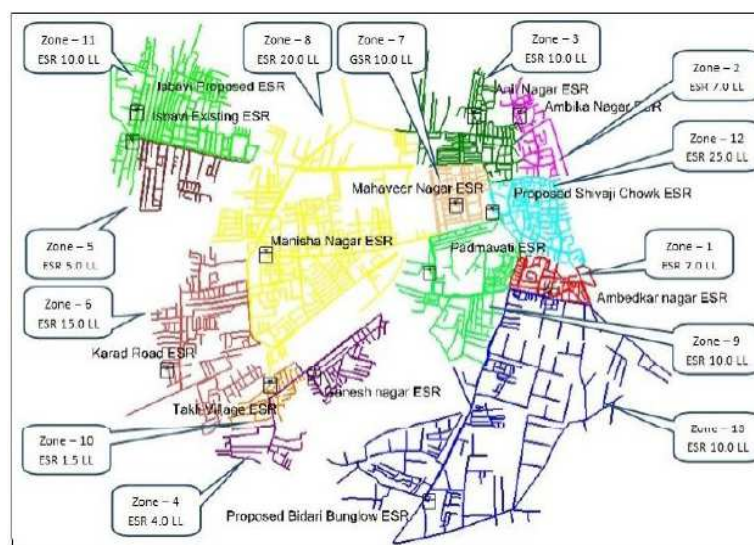
boundary of the town. It is this curvature that has given the name “Chandrabhaga” to this part of the river. The ground is sloping towards North and East. As per 2011 census, the Pandharpur Municipal Council has population of 98,923.

### Analysis of Existing Water Supply Scheme

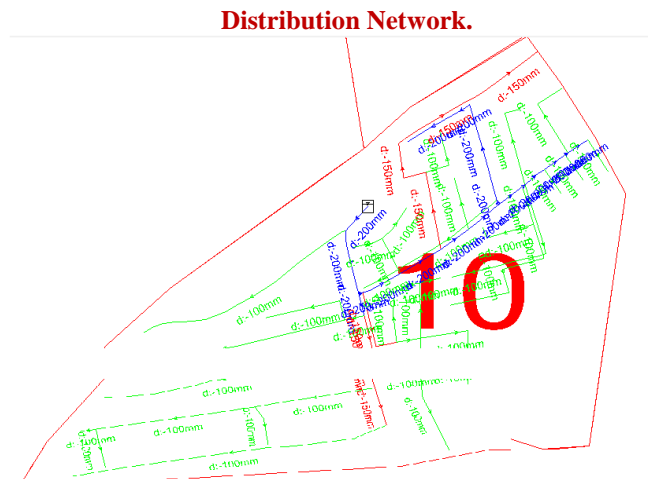
Existing water supply system consists of one underground sump, four GSRs and eleven ESRs. These service reservoirs are supplying water to the city. Since, the city is expanding rapidly; the water supply system of the city is to be designed for 24 x 7 water supply to the consumer end. As per Central Public Health and Environmental Engineering Organization (CPHEEO) manual, the distribution pipe network is to be designed for 30 years in two steps. Four GSRs are old, aged 20 years (1998) and cannot be utilized considering minimum residual head criteria of 12 m at nodal point. Also, Chauphala ESR is proposed to discard considering its life and serviceability. Moreover, UG tank of 67 LL will be utilized only for feeding ESRs. Therefore, 10 existing ESRs are utilized and 3 ESRs are proposed as show in Figure. 1. Thus, a total of 13 operational zones are formed. The city's ground levels vary from 437 m to 476 m. Thus, the zoning of the entire distribution network is planned considering the topography of the city and also to fulfill the existing ESRs for its maximum capacity.

By surveying the water supply network field, water supply network is tracked from initial location to the user end using data collected from all stations. From collected data, hydraulic model of water supply network is created using WaterGEMS software and same model of Takali zone number 10 with 59 junctions is shown in Figure. 2. In Figure. 2, 100 mm, 150 mm and 200 mm pipes are indicated by green, red and purple colors, respectively, (This is the limitation of software). From the current manual analysis, it is observed that total pipe length of 4949 m is required. The cost required for the same length with 100 mm, 150 mm and 200 mm diameter pipes is Rs 4,29,8430. While creating the model of Takali zone, water storage capacity of 1.5 LL, GL of 465 m, LSL of 477 m and FSL of 482 m is considered.

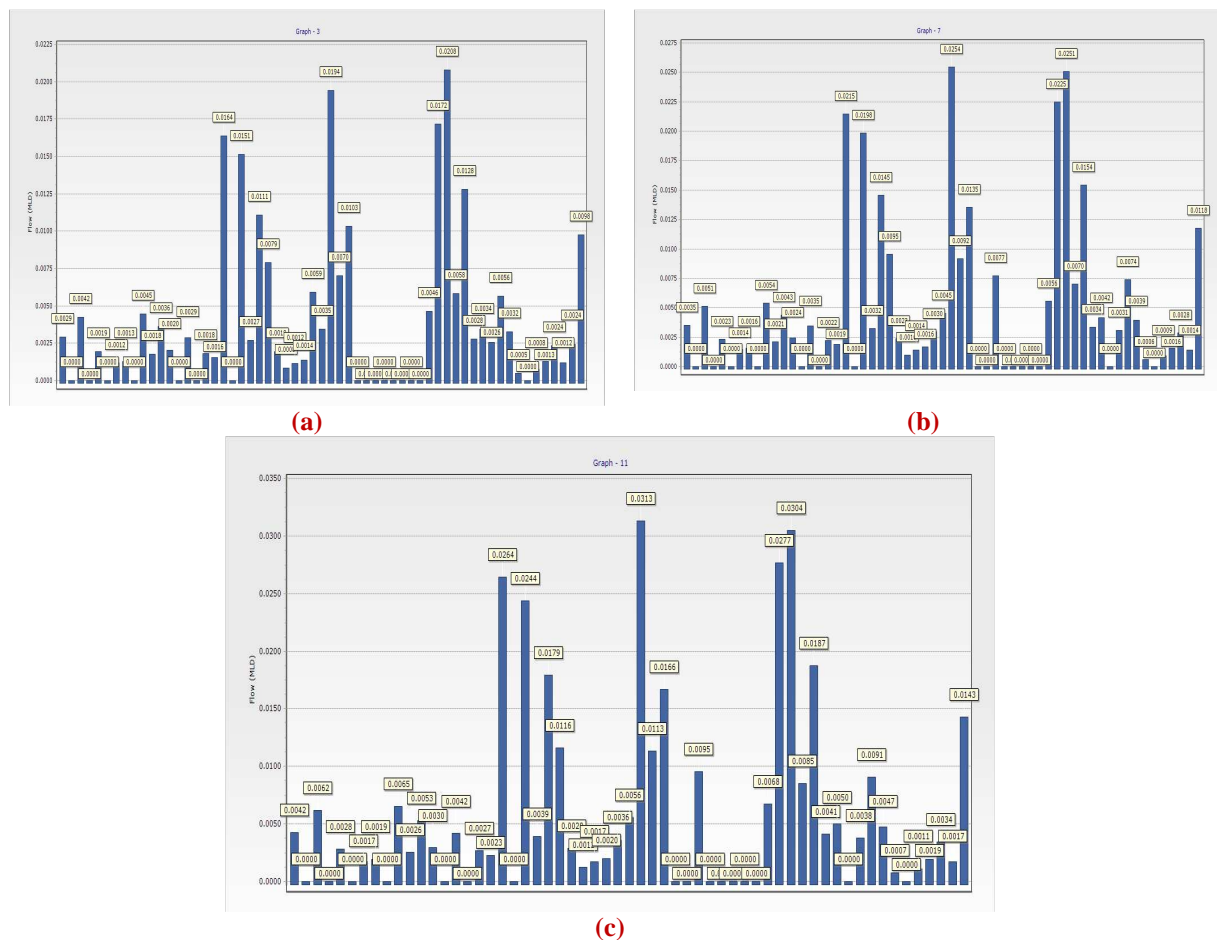
The population forecasting for 30 years from the year 2015 to 2045 is determined using arithmetic increment method and geometric method (simple and universally accepted used method). The water supply system for the Takali zone is designed for a period of 30 years with two phases. Phase-I is from the year 2015 to 2030 and Phase-II is from the year 2030 to 2045. The immediate stage-2015, intermediate stage-2030 and final stage-III with forecasted population are of 1442, 1805 and 2195, respectively.



**Figure 1: Formation of Zones of Pandharpur City for Water**



**Figure 2: Hydraulic Model of Water Distribution Network of Takali Zone (10).**



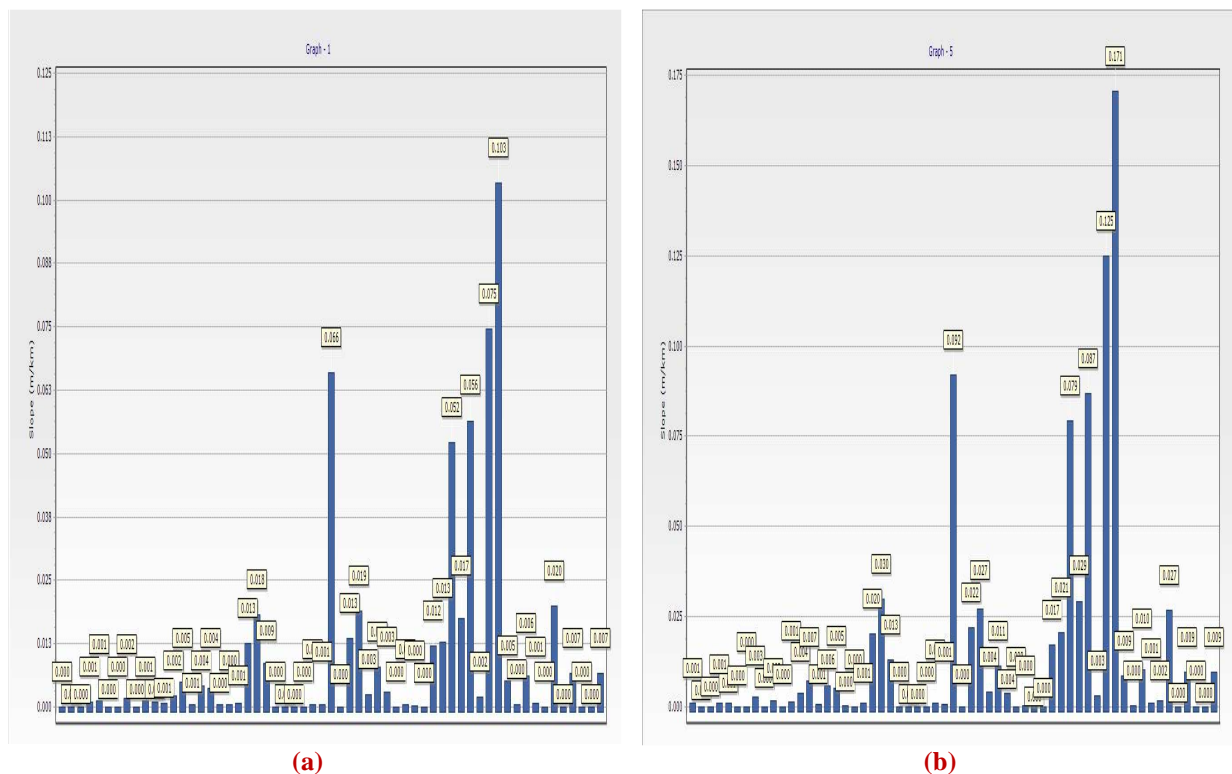
**Figure 3: Demand at Different Junctions (a) Immediate Stage-2015, (b) Intermediate Stage - 2030 and (c) Final Stage-2045.**

The development of flow (demand), head loss gradient (slope) and pressure at various junctions for immediate stage-2015, intermediate stage-2030 and final stage-2045 is studied and shown in (Pipe no label is on X-axis)-Figure. 5. (That numbers are flow (MLD) at that node and they are shown in such a way by the software.) Figure. 3 shows development of demand at various junctions. The maximum demand 0.0208 MLD is observed at junction 44 in the immediate stage 2015, as shown in Figure. 3(a). From Figure. 3(b), it is observed that the maximum demand of 0.0254

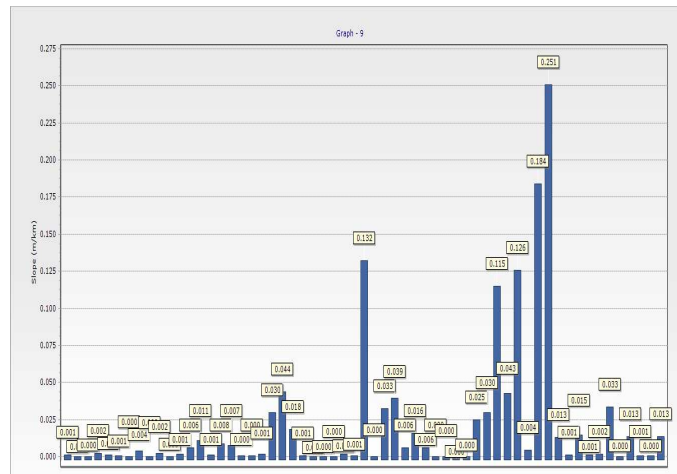
MLD is observed at junction 31 for intermediate stage 2030. Further maximum demand of 0.0313 MLD is observed at junction 31 for final stage 2045. This demand is increased due to increase in population from 1442 to 1805 and further to 2195.

The head loss effect is studied at 59 junctions for population of 1442, 1805 and 2195 at immediate stage-2015, intermediate stage-2030 and final stage-2045, respectively. The development of head loss gradient in m/km is shown in Figure. 4. Figure. 4(a) shows head loss gradient for immediate stage-2015. From Figure. 4(a), it is seen that, maximum head loss gradient is observed at junction 48. The maximum value of head loss gradient observed is 0.103 m/km. Figure. 4(b) shows the head loss gradient for intermediate stage-2030. From Figure. 4(b), it is observed that maximum head loss gradient of 0.171 m/km is observed at junction 48. Further analysis is carried out for final stage-2045 for population of 2195 and its head loss effect is shown in Figure. 4(c). From Figure. 4(c), it is clear that at junction 48, maximum head loss gradient of 0.251 m/km is observed. This is because the population increased from the immediate stage to the final stage.

The development of pressure in water supply network system should be in the range of 15–80 psi. The analysis of development of pressure at various junctions of Takali zone (zone 10) is carried out using WaterGEMS. The pressure developed at each junction is shown in Figure. 5. From Figure. 5, it is seen that the minimum pressure of 16.2 psi (everywhere the same unit is used) is developed at junction number 56, whereas maximum pressure of 27.3 psi is developed at junction 46.

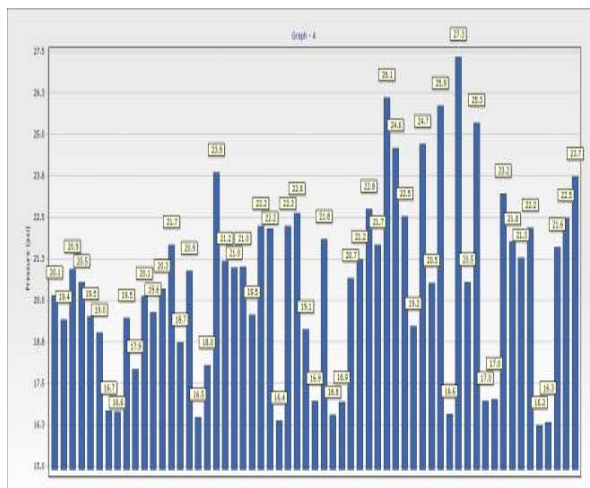




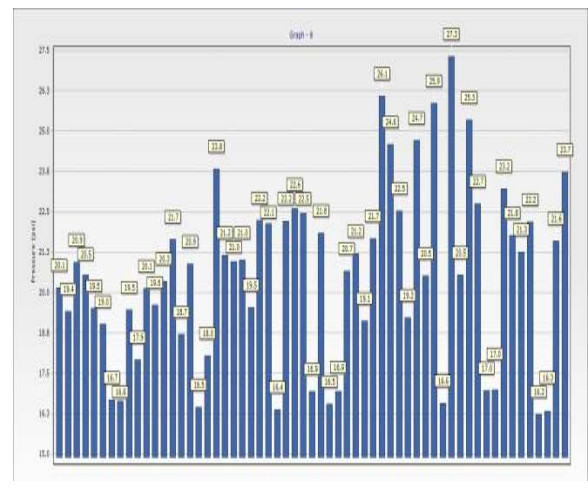


(c)

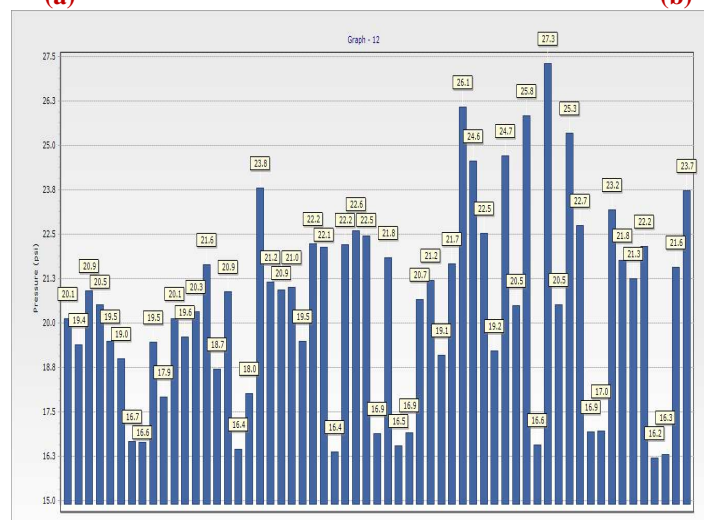
**Figure 4: Head Loss Gradient at Different Junctions (a) Immediate Stage – 2015, (b) Intermediate Stage – 2030 and (c) Final Stage–2045**



(a)



(b)

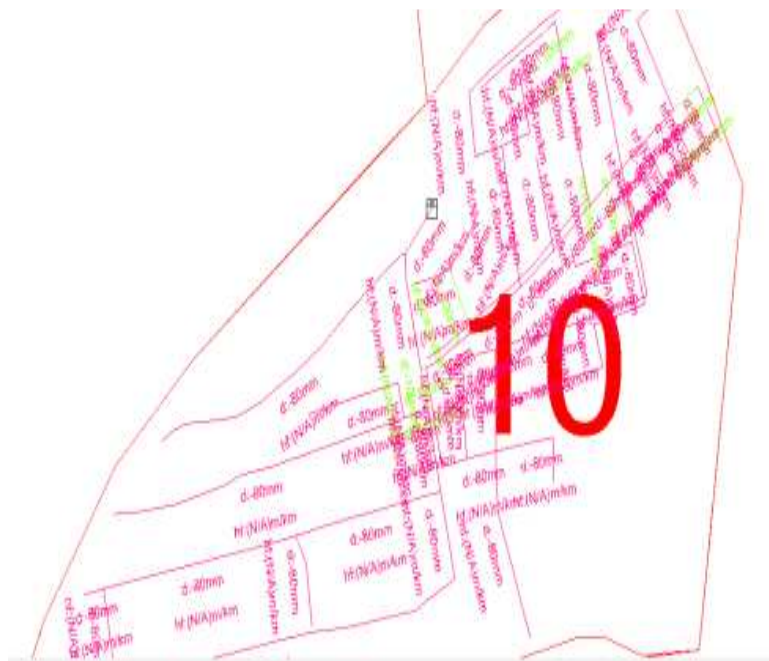


(c)

**Figure 5: Pressure at Different Junctions (a) Immediate Stage–2015, (b) Intermediate Stage–2030 and (c) Final Stage–2045.**

### Optimization of Existing WSS using Darwin Approach

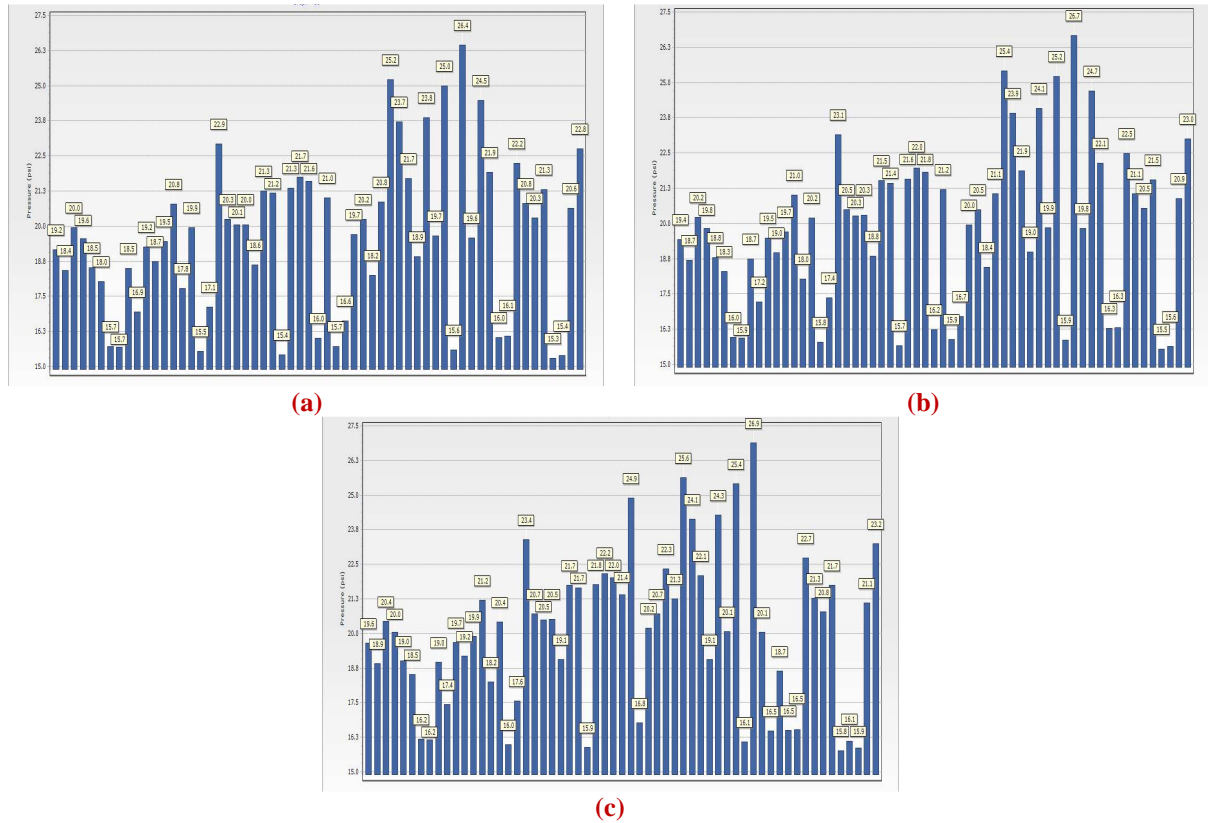
A module of WaterGEMS software named 'Darwin Designer' is used to obtain maximum benefit of water supply system. Darwin Designer is an efficient method of designing new pipe layouts and pipe rehabilitation projects. It allows designing network for an existing model, either manually or with efficient genetic algorithms, in a more automated fashion. It also allows for multiple designs to be presented, so the best possible solution can be found. Solutions can also be exported into a new scenario for use in an existing water system. This software optimizes the water supply network on the basis of various constraints, viz., pressure range, flow velocity, etc. This module is based on generic algorithm, which provides multi-objective optimization. In this paper, objective function is to minimize cost for all three stages. The different optimized solutions are provided by the software with correct ranking. In this paper, optimized cost condition with various pipe diameters is studied.



**Figure 6: Optimized Pipe Network of Takali Zone at a Immediate Stage-2015.**

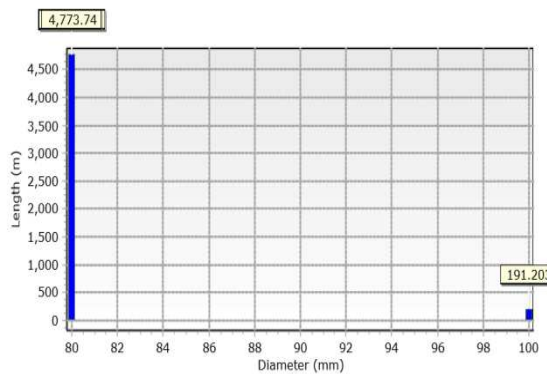
## RESULTS AND DISCUSSIONS

In this study, Darwin optimization module which is based on genetic algorithm is used to obtain optimal pipe network system. The main objective of the work is optimization of cost required for water supply system. As per the Darwin optimization approach, three different optimized solutions are obtained. The best solution for each stage is considered. The optimization is carried out with determining the development of pressure at various junctions. The objective is achieved by reducing the diameter and the length of pipes. The optimized pipe network of Takali zone (zone 10) is shown in Figure 6. The pink color lines show 80 mm diameter of pipes and green color lines show 100 mm diameter of pipes.

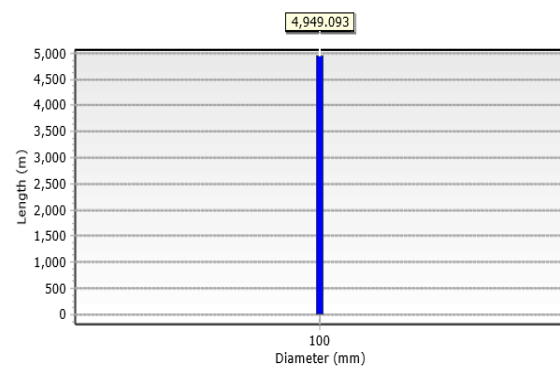


**Figure 7: Optimized Solutions for Pressure at Different Junctions (a) Immediate Stage – 2015, (b) Intermediate Stage – 2030 and (c) Final Stage – 2045.**

The effect of these pipe diameter and length on development of pressure at various junctions is shown in Figure. 7. Figure 7(a) – Figure 7(c) shows the optimized solution with the development of pressure at various junctions from the stage of the immediate stage – 2015, intermediate stage – 2030 and final stage – 2045. From Figure 7(a), it is observed that maximum pressure of 26.4 psi is developed at junction number 46 and minimum pressure of 15.3 psi is developed at junction number 56 for immediate stage – 2015. Further, maximum pressure of 26.7 psi and minimum pressure of 15.3 psi is developed at junction number 46 and 56 for intermediate stage – 2030, respectively, as shown in Figure 7(b). Similarly, maximum pressure of 26.9 psi is developed at junction number 46 and minimum pressure of 15.3 psi is developed at junction number 56 for final stage – 2045.

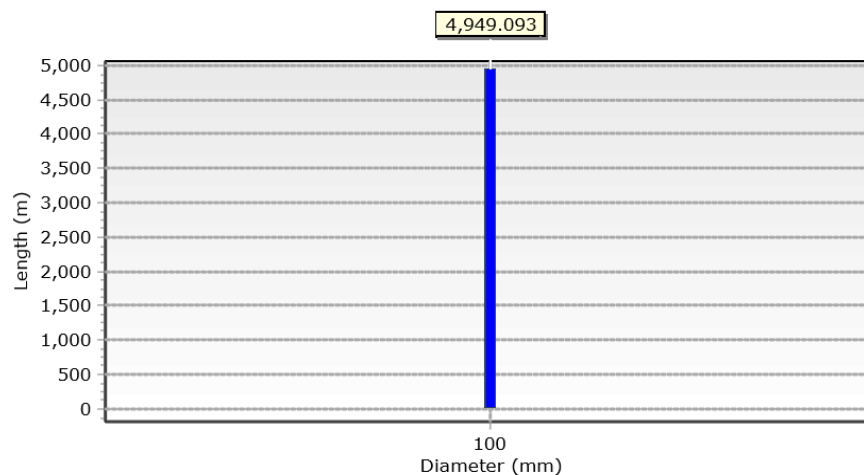


**(a)**



**(b)**





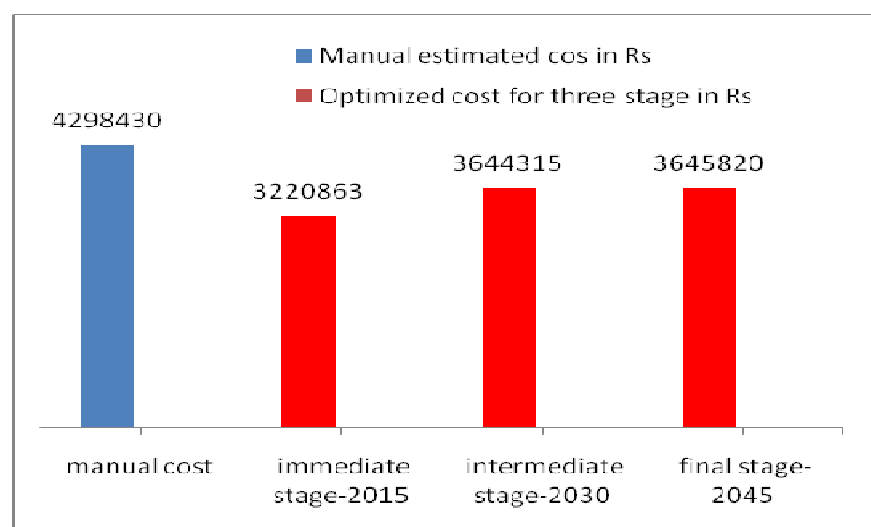
(c)

**Figure 8: Optimized Solutions of Pipe Diameter with Total Length Required for Water Supply Network for Immediate Stage – 2015, Intermediate Stage – 2030 and Final Stage – 2045.**

The pipe diameter with total length required for water supply network for immediate stage – 2015, intermediate stage – 2030 and final stage – 2045 is shown in Figure 8.

Figure 8(a) shows pipe diameters with total length required for pipe network. The pipe length of 4773.74 m (80 mm diameter) and 191.203 m (100 mm diameter) is required for Takali zone for immediate stage – 2015. Figure. 8(b) shows water supply network of total length of 4949.093 m with 100 mm pipe diameter for intermediate stage – 2030 as well as for final stage – 2045.

The cost required for pipe network is obtained using Darwin optimization approach is shown in Figure 9. Figure. 9 shows the cost estimation for existing, immediate stage – 2015, intermediate stage – 2030 and final stage – 2045 water supply system. The manual estimated cost for the year 2015 is Rs. 4,29,8430, while optimized cost for immediate stage – 2015, intermediate stage – 2030 and final stage – 2045 is Rs. 3,22,0863, 3,64,4315 and Rs. 3,64,5820, respectively. The maximum amount of Rs. 10,77,567, Rs. 65,4115 and Rs. 65,2610 are reduced using optimization approach. The maximum 33.45% of cost optimization is achieved through pipe network optimization.



**Figure 9: Comparison of Manual Cost with Optimized Cost at (a) Immediate Stage–2015, (b) Intermediate Stage–2030 and (c) Final Stage–2045.**

## CONCLUSIONS

The design for 24 x 7 water supply, modeling and optimization of network system is carried out in this study. Initially, manual analysis was carried out for one zone by forecasting the population and their demand. Based on this study, the effect of population on demand, head loss gradient and pressure development is carried out. Further optimization of the same network is conducted using Darwin approach. The aim was to minimize the cost of pipe network. Based on this study, following conclusions are summarized.

- From the analysis, it is observed that as population increases, demand of water supply increases. It is clearly observed that demand has increased from 0.0208 MLD to 0.0315 MLD from immediate stage – 2015 to final stage – 2045.
- It is also observed that the head loss of 0.103 m/km, 0.171 m/km and 0.251 m/km is observed for immediate stage – 2015, intermediate stage – 2030 and final stage – 2045, respectively.
- From Darwin's optimization study, it is observed that cost of the pipe network is reduced by 33.45% with the reduction of development of pressure by balancing it at various places.

## REFERENCES

1. J. Sun, R. Wang, X. Wang, H. Yang and J. Ping, "Spatial cluster analysis of bursting pipes in water supply networks " *Procedia Eng.* 70 ( 2014 ) 1610–1618.
2. Gustavo Meirelles Lima, Bruno Melo Brentan and Edevar Luvizotto Jr. "Optimal design of water supply networks using an energy recovery approach" *Renew. Energ.* 117 (2018) 404–413.
3. T. M. Walski, *A history of water distribution*, J. Am. Water Works Assoc. 98 (3) (2006) 110–121.
4. Gustavo Meirelles Lima, Bruno Melo Brentan and Edevar Luvizotto Jr. "Optimal design of water supply networks using an energy recovery approach " *Renew. Energ.* 117 (2018) 404–413].
5. Hamada M. *Water supply system: planning aspects. Critical urban infrastructure handbook*, 11, Boca Raton: CRC; 2014.
6. L. W. Mays, *Water distribution systems handbook*, McGraw-Hill, New York, 2000., A. Di Nardo, M. Di Natale, G. F. Santonastaso, V. G. Tzatchkov, V. H. Alcocer-Yamanaka, *Water network sectorization based on graph theory and energy performance indices*, *J. W. Res. Plan. Manage.*, 140–5 (2014), 620–629.
7. Elnesr et al. "Simulation of water distribution under surface dripper using artificial neural networks" *Computers and Electronics in Agriculture* 143 (2017) 90–99.
8. Ayad et al. "Integrated approach for the optimal design of pipeline networks." *Alex. Eng. J.* (2018) 57, 87–96.
9. Zabih et al. "A novel robust optimization approach for an integrated municipal water distribution system design under uncertainty: A case study of Mashhad" *Comput Chem Eng.* 110 (2018) 13–34.
10. L. F. R. Reis, R. M. Porto, F. H. Chaudhry, *Optimal location of control valves in pipe networks by genetic algorithm*, *J. Water Resour. Plan. Manag.* 123 (6) (1997) 317–326, [https://doi.org/10.1061/\(ASCE\)0733-9496\(1997\)123:6\(317\)](https://doi.org/10.1061/(ASCE)0733-9496(1997)123:6(317)).

11. J. Saldarriaga and C. A. Salcedo, *Determination of optimal location and settings of pressure reducing valves in water distribution networks for minimizing water losses in 13th Computer Control for Water Industry Conf. – CCWI, Procedia Eng.*, 119, 2015, pp. 973–983, <https://doi.org/10.1016/j.proeng.2015.08.986>.
12. I. Basupi and Z. Kapelan, *Flexible water distribution system design under future demand uncertainty, J. Water Resour. Plan. Manag.* 141 (4) (2015), 04014067, [https://doi.org/10.1061/\(ASCE\)WR.1943-5452.0000416](https://doi.org/10.1061/(ASCE)WR.1943-5452.0000416).
13. J. Marques, M. Cunha, D. Savic and O. Giustolisi, *Water network design using a multiobjective real options framework, J. Optim.* (2017) 1e13, <https://doi.org/10.1155/2017/4373952>.
14. Alperovits, E. and Shamir, U. (1977). *Design of Optimal Water Distribution Systems. Water Resour. Res.*, 13(6):885–900.
15. Goldberg, D. E. and Kuo, C. H. (1987). *Genetic Algorithms in Pipeline Optimization. J. Comput. Civil. Eng.*, 1(2) 128–141. doi: 10.1061/(ASCE)0887-3801(1987)1:2(128).
16. Lansey, K. E. and Mays, L. W. (1989). *Optimization model for design of water distribution systems. Reliability analysis of water distribution systems, L. R. Mays, ed., ASCE, Reston, Va.*

